

Jörn Pacht

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SIGNAL ARRANGEMENTS**

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AUTHOR

Prof. Dr. Joern Pachtl

Technical University Braunschweig, Institute of Railway Systems Engineering and Traffic Safety

Pockelsstrasse 3, D-38106 Braunschweig, Germany

Phone: 49 531 391 3380, Fax: 49 531 391 5955, email: j.pachtl@tu-bs.de

ABSTRACT

Blocking time analysis is an approved and widely adopted method to calculate and describe the operational usage of railroad infrastructure by train movements. It is the theoretical basis for the most advanced software solutions for train scheduling and capacity management. The basic idea behind blocking time analysis has been recently described in several publications including presentations at TRB meetings. Although the principle of blocking time analysis is easy to understand, there sometimes occur problems in correct application of this method for specific signal arrangements. This paper explains practical solutions for the calculation of the approach time of different block signal systems and for handling the blocking time of block overlaps. These solutions are valuable both for correct use of existing software systems and for development of new systems.

THE BLOCKING TIME MODEL

Effective capacity management of railroad infrastructure requires a model to exactly describe how the infrastructure is operationally used by train movements (1). Such a model is the basis both for advanced computer-based scheduling systems and for determination of the capacity of railroad infrastructure. A model that meets these requirements is the blocking time model. A fundamental introduction to the idea behind blocking time analysis was provided in a presentation at TRB's 83rd Annual Meeting in 2004 (2). Since the following sections require understanding of blocking time theory, the basic idea is explained here in an abridged form. For more details see the paper (2) or the textbook "Railway Operation and Control" (3).

The blocking time is the total elapsed time a section of track (e.g. a block section, an interlocked route) is exclusively allocated to a train movement and therefore blocked for other trains. It begins with issuing movement authority for this section and ends after the train has completely left the section and all signaling devices have been reset to normal state. The blocking time of a track section is usually much longer than the time the train occupies the section. In a territory with lineside signals, the blocking time of a block section consists of the following time intervals:

- the time for clearing the signal
- a certain time for the engineer to view the clear aspect at the signal that gives the approach indication to the signal at the entrance of the block section (this can be a block signal or a separate distant signal)
- the approach time between the signal that provides the approach indication and the signal at the entrance of the block section (not required for trains with a scheduled stop before the block section)
- the time between the block signals
- the clearing time to clear the block section and—if required—the overlap with the full length of the train
- the release time to "unlock" the block system

In a territory with cab signaling, the principle is quite similar but the approach time is now the time the train runs through the stopping distance that is signaled by the cab signal system. Drawing the blocking times of all block sections a train occupies into a time-over-distance diagram leads to the so-called "blocking time stairway" (Figure 1).

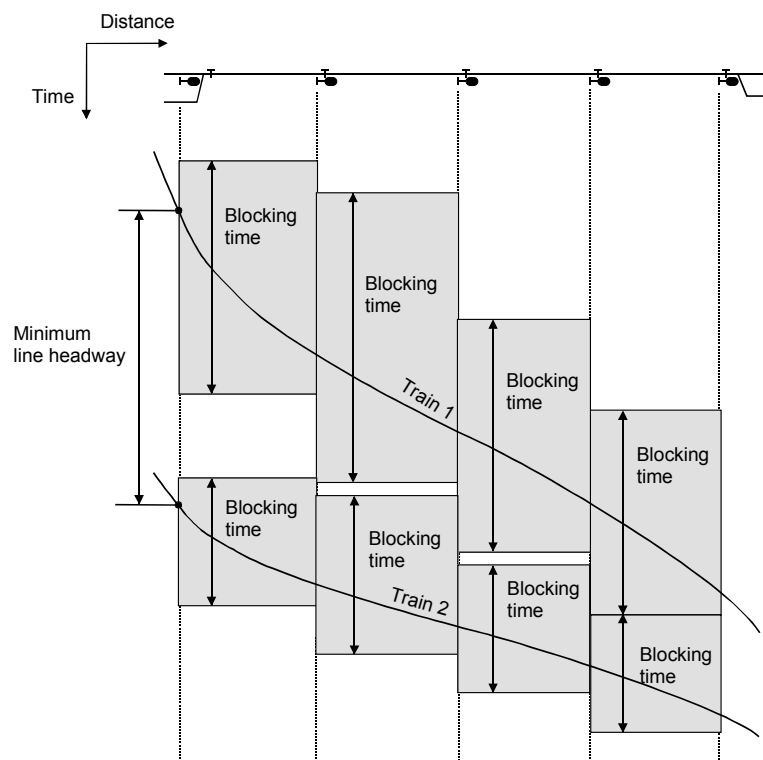


Fig.1: Blocking time stairways of two trains following each other at minimum line headway.

The blocking time stairway represents perfectly the operational use of a line by a train. With the blocking time stairway, it is possible to determine the minimum line headway of two trains by the simple rule that blocking time stairways of following trains must not overlap at any point of the run.

Although the basic principle of the blocking time model is simple, there are frequently asked questions of how to apply blocking time analysis to special signal and interlocking arrangements. One kind of questions is

related to correct calculation of the approach time for different block signal systems. Another kind of questions concerns problems of handling block overlaps in specific interlocking arrangements. The following sections deal with both kinds of questions.

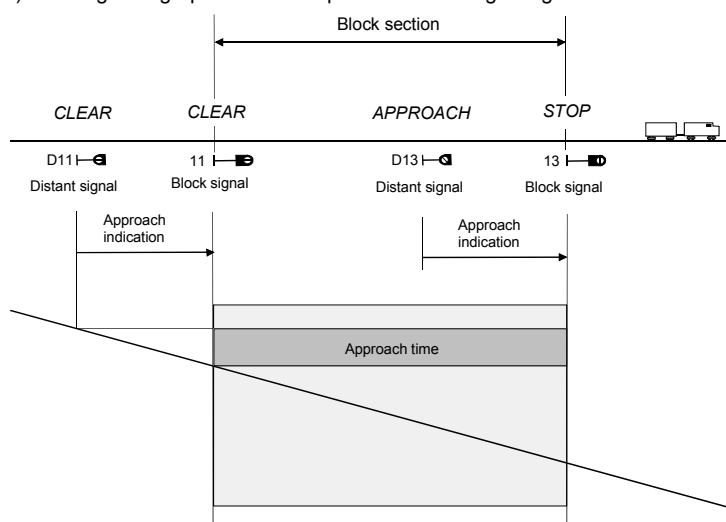
APPROACH TIME IN THREE- AND FOUR-ASPECT SIGNALING

Block signal systems can be classified by two ways:

- by the number of signal aspects,
- by the number of block sections a signal provides information for.

The two classifications are not directly related but are often confused. A correct understanding is essential for blocking time calculations, especially for correct calculation of the approach time. Today the most common kind of block signal system is three-aspect signaling. In three-aspect signaling, a train will get three successive signal aspects when approaching a stop signal: clear – approach – stop. In North America, three aspect signaling is usually combined with two-block signaling. That means that every signal can display all three signal aspects thus providing information for two block sections (Figure 2b). But it is also possible to run three-aspect signaling with two-aspect signals. In such a system every block signal will have a distant signal that is located at the stopping distance (Figure 2a).

a) Blocking time graph for three-aspect one-block signaling



b) Blocking time graph for three-aspect two-block signaling

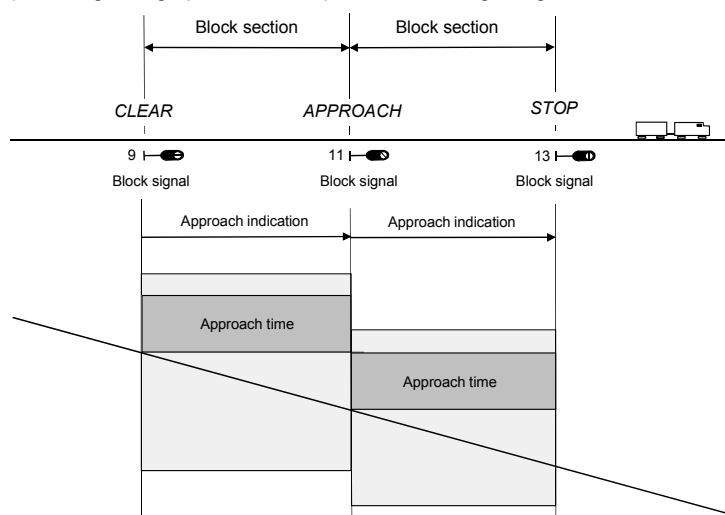


Fig. 2: Different kinds of three-aspect block signaling

Block signals can show stop/clear while distant signals can show approach/clear. Therefore, a train that is approaching a stop signal will get the same signal aspect sequence as described above: clear – approach – stop. But such a signal arrangement is not two-block but rather one-block signaling. A block signal can only

provide information for the block section ahead but no approach indication for the next block signal. Although no longer common on modern North American railroads (4, 5), one-block signaling with three aspects is widely used outside of North America on lines where the block length is much greater than the braking distance. Since the running time between the signal that provides the approach indication and the signal that governs entrance to the block section (the approach time) is part of the blocking time, the approach indication should be given as late as possible. Otherwise line capacity will decrease. On European railroads with their high traffic density (on average five times higher than in North America) and their short stopping distances (e.g. in Germany the regular stopping distance on lines with a maximum speed of 100 mph [160 km/h] is just 3050 ft [1000 m]), three-aspect one-block signaling with distant signals is a very frequent occurrence (6). Two-block signaling is only used on lines where the stopping distance is about the same length as the block sections. As an example, in Germany two-block signaling will only be used if the block length exceeds the regular stopping distance by less than 985 ft [300 m]. In North America, due to heavy freight operations, stopping distances are much longer and often meet the average block length. Therefore, two-block signaling is generally more appropriate. Even on long block sections that exceed the stopping distance, two-block signaling is often acceptable due to a lower density of traffic. Blocking time analysis is the appropriate method to evaluate the influence of the point where approach indication is given, to line capacity. In blocking time calculations three-aspect signaling is easy to handle. In systems with one-block signaling, approach time begins at the distant signal, in systems with two-block signaling, it begins at the last block signal in approach to the signal at the entrance of the block section.

In recent decades, as a result of running heavy trains at higher speeds, many railroads in North America and abroad introduced four-aspect block signal systems. In a four-aspect block signal system, a train that is approaching a stop signal will see a sequence of four successive signal aspects. There are two kinds of four-aspect signal systems which differ in the role of the fourth signal aspect:

- four-aspect signaling with an “advance approach” aspect (Figure 3),
- four-aspect signaling with an “approach medium” or an “approach limited” aspect (Figure 4).

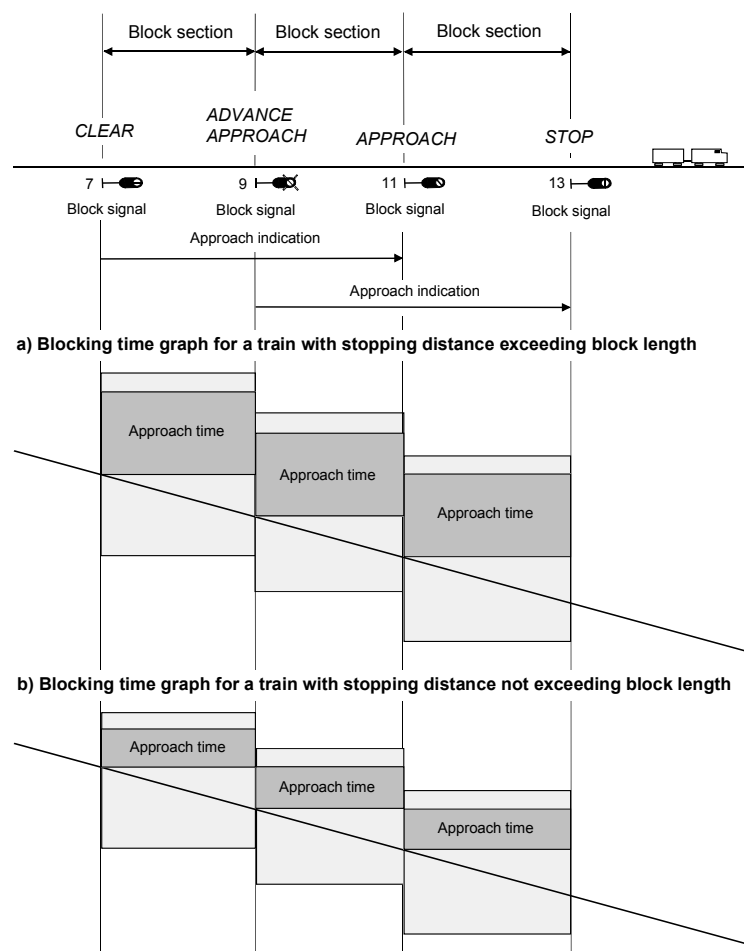


Figure 3: Four-aspect signaling with an “advance approach” aspect

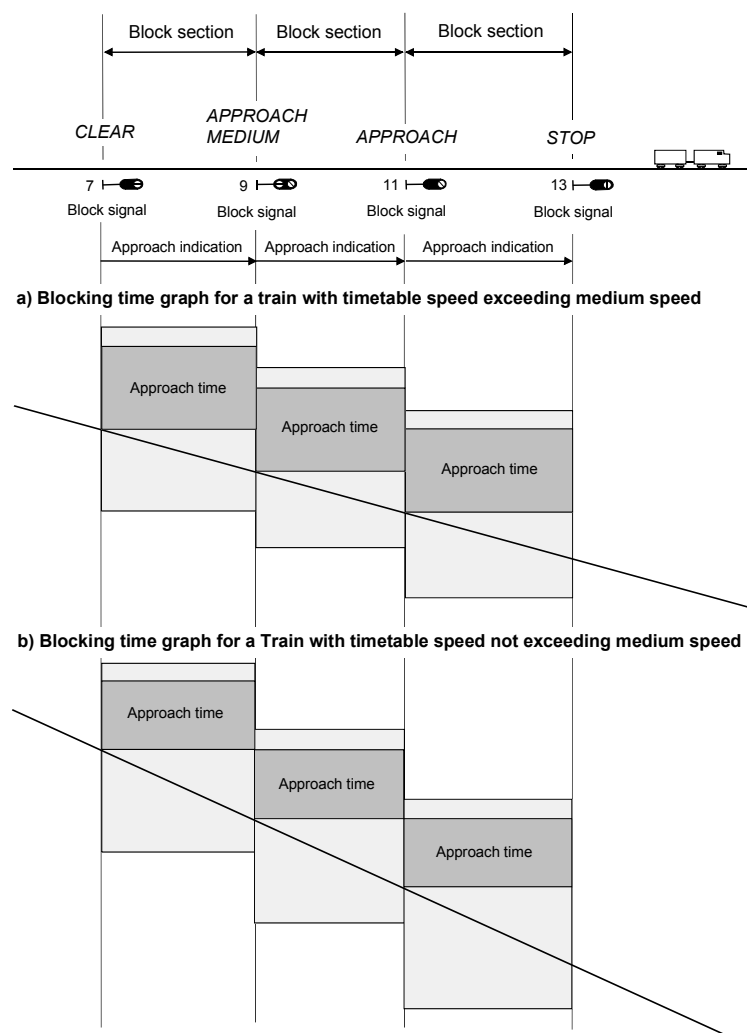


Fig. 4: Four-aspect signaling with an "approach medium" aspect (same principle also possible with "approach limited" aspect)

Both kinds of signaling are very common on North American railroads (7, 8). Although the two signal systems seem similar, they have very different effects on operation. A paper presented at TRB's 83rd Annual Meeting in 2004 by the University of Illinois at Urbana/Champaign describes the different effects of these two kinds of signaling on train brake control (9). Here, these systems are compared from the viewpoint of blocking time analysis.

In a block signal system with an "advance approach" aspect, the engineer gets information as to three blocks ahead. That means that this signal system is based on the principle of three-block signaling. In a system with an "approach medium" or an "approach limited" aspect, the situation is different (the decision if an "approach medium" or an "approach limited" aspect should be used depends on the block length). This system of staggered speed signaling is still based on the principle of two-block signaling. The "approach medium" or "approach limited" indication just says that the next signal must be passed at medium or limited speed, but that does not necessarily mean that the next signal will be at "approach". In most cases, it will be at "approach", but if that signal protects an interlocking it could also show another aspect. Although there are four signal aspects, the engineer gets only information of two block sections ahead.

When blocking time analysis is applied on a line with four-aspect signaling, the question will be at what signal the approach time begins. In a system with an "advance approach" aspect, it depends on the stopping distance of the train. At the signal that shows the "advance approach" aspect, the engineer gets the information that the second signal will be at stop. For a train with a stopping distance that exceeds the block length, the approach time begins at that signal. If the stopping distance does not exceed the block length, the approach time begins at the signal that shows the "approach" aspect. This principle of signaling is especially valuable on lines where trains with different braking characteristics run on the same track.

In a system with an "approach medium" aspect, the signal that is the beginning of the approach time depends on the speed of the train. For a train with a maximum speed greater than medium speed, the approach

Fig. 6: Example interlocking diagram of the New York subway with overlapping signal control lengths (Station King's Highway on Jamaica Line, copyright of the drawing: Karl A. Steel)

Different Handling of Overlaps

The handling of pure block overlaps in blocking time analysis is quite simple. The blocking time of the overlap is only considered as part of the blocking time of the block section but it is not necessary to show a separate blocking time graph for the overlap. This can be done because the blocking time of the overlap influences the clearing time of the block section but it would never lock other movements. In Figure 7 this applies to signals 11, 13, and 17.

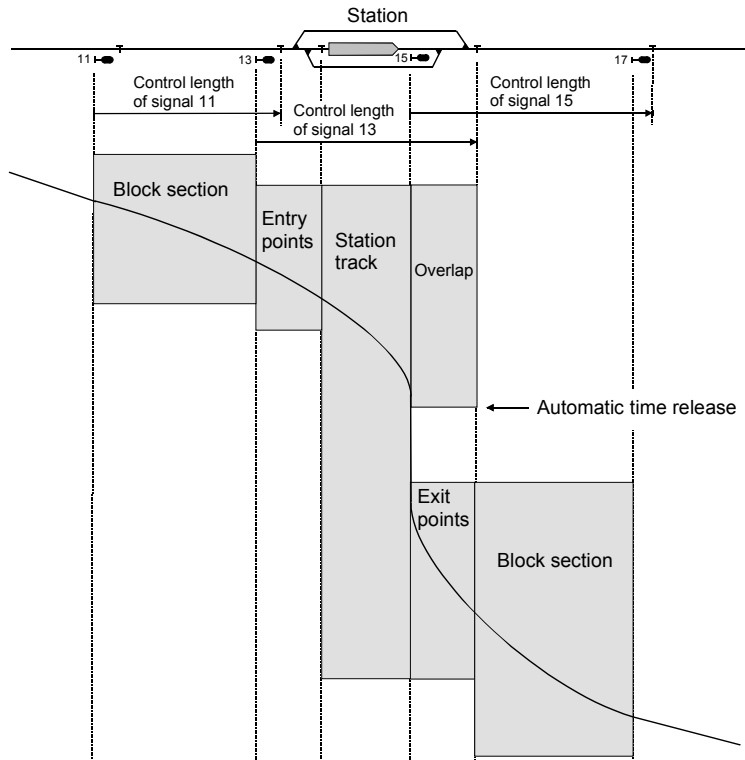


Fig. 7: Different handling of overlaps in the blocking time graph

But in station areas on railroads where overlaps are used, there are often successive interlocking signals within the same home signal limits (a situation that is also not typical on North American standard railroads). There, an interlocked route leads from the home signal to another signal that is often called a destination or exit signal (the term exit signal is used here in a different way from North American standard railroad terminology). In complex interlockings, the overlap behind the exit signal of an interlocked route may exceed into the switch zone behind that signal. In FIGURE 7 this applies to signal 15. So, as long a route is set up at the home signal the switches within the overlap are locked. The handling of such interlocked overlaps in blocking time analysis is different from pure block overlaps. During the blocking time of the overlap, other routes that lead through the overlap are locked. The overlap will release after the train has stopped (usually effected by automatic time release). Thus, the blocking time of the overlap may end at a time when the track section in approach to the signal is still blocked. That is why the blocking time graph must contain an extra blocking time for the overlap.

Such interlocked overlaps produce route conflicts which reduce the capacity of an interlocking. Railroads that use interlocked overlaps developed different principles to minimize the probability of having routes being locked by overlaps of other routes.

“Overlapping” overlaps

In German interlockings, overlaps of different routes set up at the same time may overlap each other (Fig. 10). For this purpose, trailing points within the overlap remain unlocked. Due to the standard intermittent automatic train protection system that is installed on all signaled lines in Germany, the probability of sliding past a stop signal is quite low. It is not assumed that two trains will run into their overlaps at the same time. In track sections where overlaps overlap each other, the blocking times of these overlaps will overlap, too. If the blocking time analysis is done manually, the researcher will have to obey the rules of overlapping overlaps. In a computerized model, e.g. as used for computer-based scheduling, it would be nicer if blocking times were never allowed to overlap each other. That would simplify the automatic search for a clear train path and the calculation of required minimum headways. This can be achieved by using a modified infrastructure model in the computer

database. This model uses fictive tracks that do not exist in the real trackwork. These tracks would take overlaps to avoid an overlapping with overlaps of other routes. The design of fictive tracks must meet the following constraints (Figure 8):

- Overlaps that may overlap with each other in the real infrastructure must be completely separated in the logical model.
- An overlap that leads into a fictive track must touch all train routes that are locked by this overlap.
- A train route must never run over a fictive track.

The example of Figure 8b meets these constraints by having a fictive track to take the overlap of signal 21 and by having this overlap joined the common (real) track behind the end of the overlap of signal 11. Thus, the two overlaps no longer overlap each other. But a train route that starts at signal 11 will be locked by the overlap of signal 21. Since a train route that starts at signal 21 runs over the real track and not over the fictive track, that train route will be locked by the overlap of signal 11. In FIGURE 8b the overlap of signal 21 just seems to be longer than in the real trackwork. The fictive track should be given a logical length so that the length of the overlap of signal 21 will exactly meet the real length. Thus, the logical computer model will act like a real infrastructure with overlapping overlaps.

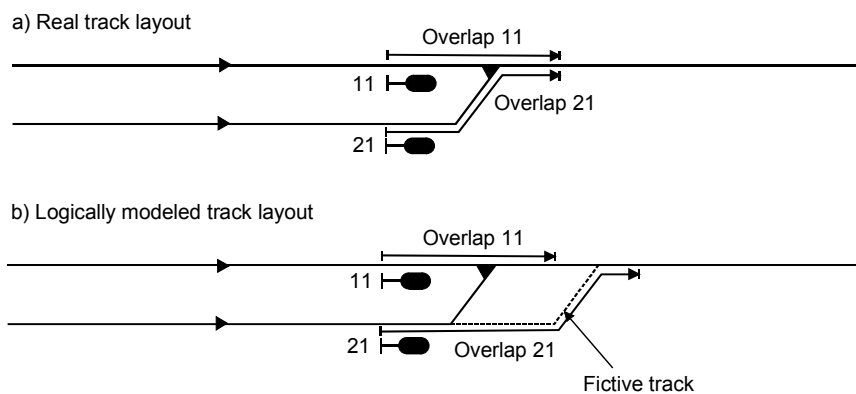


Fig. 8: Proposal for handling “overlapping” overlaps in a blocking time model

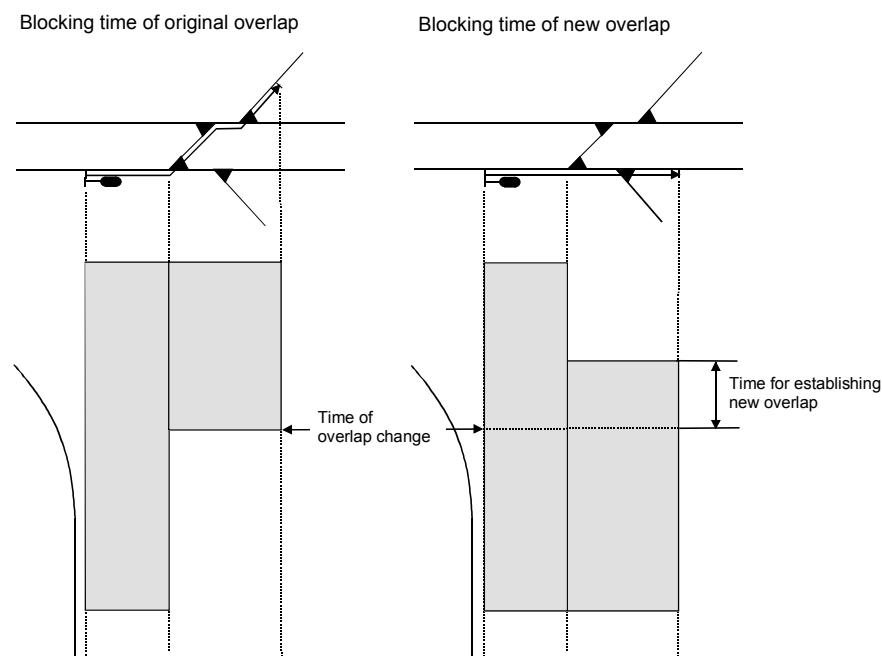


Fig. 9: Blocking time of a swinging overlap

Swinging overlaps

The described principle of overlapping overlaps is only used by railroads which follow German principles. Other railroads in the world prefer another principle of overlap logic that is called “swinging overlaps”. In a swinging overlap, switches within the overlap are interconnected in a locking sequence that allows changing the overlap without restoring the signal and canceling the route. Figure 6 contains a number of swinging overlaps which can be identified by splitting control lines within the overlap. The locking of the facing point switch where the overlaps diverge will release after the new overlap has been established. For the working of the locking procedure of a swinging overlap see (2). Normally, the changing of the overlap is initiated automatically when another train route is going to run through the overlap.

The blocking time of the old overlap behind the splitting switch ends after this switch has been thrown. The blocking time of the new overlap behind the splitting switch begins with establishing the new overlap. Thus, during the time for building the new overlap, both the old and the new overlap are blocked at the same time (Figure 9).

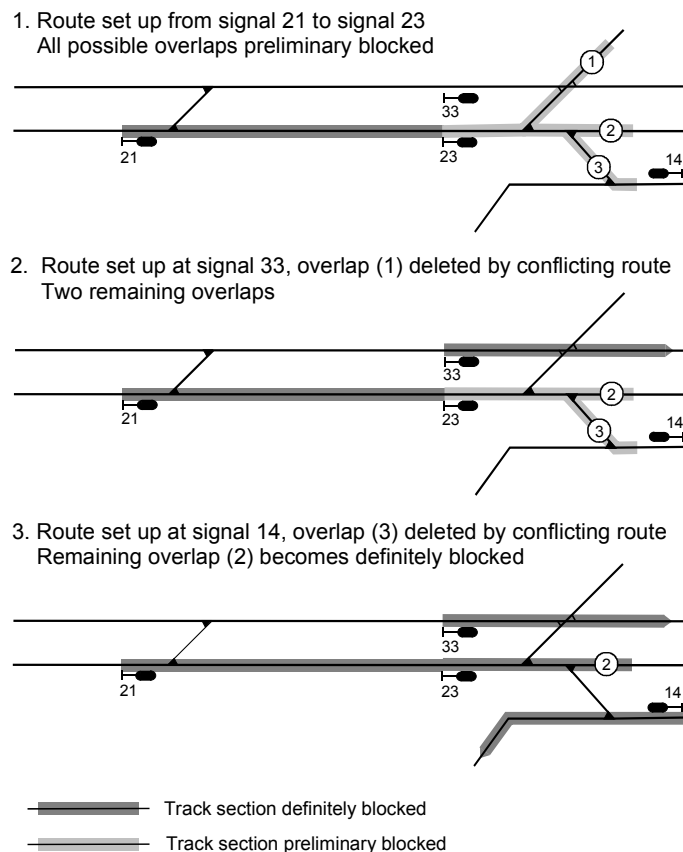


Fig. 10: Proposal for handling of swinging overlaps in software for scheduling and capacity research

There is today no software for scheduling or capacity research on the market that can deal with swinging overlaps. In difference to overlapping overlaps, there is also no practical solution using fictive tracks to model swinging overlaps. A possible way to implement swinging overlaps in future software versions could be to use a special kind of blocking time. When a route is set up a preliminary blocking time will be put on all possible overlaps (Figure 10). These blocking times are still in some kind of interim state. If a train route is going to cross one of these overlaps and there are at least two possible overlaps, the preliminary blocking time of the concerned overlap will be deleted. If there is only one overlap left, the blocking time of that overlap will become final.

CONCLUSIONS

Accurate capacity analysis or scheduling requires a complete understanding of the effect of the signal system on train movement. Blocking time analysis is a universal method to describe the operational usage of railroad infrastructure by train movements. Although the basic principle is simple, specific signal arrangements may require a specific handling. Before analysis of train movement can be conducted, a detailed analysis of the effect of the signal system on train movement must be made.

The main problem in modeling block signal systems with blocking times is the correct calculation of the approach time as part of the blocking time of the block section. The approach time depends on the aspect sequence of a block signal system. The main point is not the number of signal aspects (three- or four-aspect signals) but the number of sections a signal provides information for. In complex interlockings, problems may occur in handling blocking time of interlocking overlaps. Some problems can be solved by implementation of fictive tracks into the data model of the infrastructure while others cannot. The handling of swinging overlaps is not yet possible with software systems currently on the market. But there are suggested solutions how that functionality could be integrated in coming software versions.

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